

SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN that we, Yasunori SUZUKI, a subject of Japan and residing at Yokohama-shi, Kanagawa, Japan and Tetsuo HIROTA, a subject of Japan and residing at Minato-ku, Tokyo, Japan have invented certain new and useful improvements in

"TRANSMITTER"

and we do hereby declare that the following is a full, clear and exact description of the same; reference being had to the accompanying drawings and the numerals of reference marked thereon, which form a part of this specification.

TRANSMITTER

BACKGROUND OF THE INVENTION

Technical Field

5 The present invention relates to a radio base station transmitter having N transmission channels and, more particularly, to a radio base station transmitter adapted to suppress the creation of nonlinear distortions by power amplifiers.

Prior Art

10 A multi-port amplifier configuration has been proposed which permits reduction of the power consumption of N-channel amplifiers and implementation of their redundant configuration.

Figs. 1 and 2 show conventional multi-port amplifiers disclosed in Japanese Patent Application Laid-Open No. 10-209777.

15 Letting N represent an integer equal to or greater than 2, the multi-port amplifier comprises: an input side multi-port directional coupler 10 which divides and combines N input signals x_1, \dots, x_N into signals of N channels; N amplifiers $33_1, \dots, 33_N$ which amplify the output signals of the N channels by parallel operation; an output side multi-port directional coupler 40 which
20 divides and combines the outputs from the N amplifiers to provide N output signals u_1, \dots, u_N ; and linearizers $20_1, \dots, 20_N$ each provided in the stage preceding one of the N amplifiers, for preimparting a compensating distortion to the signal of one of the N channels to cancel a nonlinear distortion which is created by the amplifier.

25 The input side digital multi-port directional coupler 10 can be formed by one or more $\pi/2$ hybrids HB each having two input ports IP_1, IP_2 and two output ports OP_1, OP_2 as shown in Fig. 2A. The relationships between two

inputs x_1 , x_2 and two outputs y_1 , y_2 of the $\pi/2$ hybrid HB are expressed by the following equation.

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} x_1 + jx_2 \\ jx_1 + x_2 \end{bmatrix} \quad (1)$$

where the complex number x represents a $\pi/2$ phase shift. That is, the signal x_1 to the first input port IP_1 is divided into two, one of which is output to the first output port OP_1 of the original channel in phase with the input signal x_1 and the other of which is output to the second output port OP_2 $\pi/2$ out of phase with the input signal x_1 . Similarly, the input signal x_2 to the second input port IP_2 is divided into two, one of which is output to the second output port OP_2 of the original channel in phase with the input signal x_2 and the other of which is output to the second output port OP_1 $\pi/2$ out of phase with the input signal x_2 . Setting a matrix T_1 to

$$T_1 = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \quad (2)$$

a four-port (4 inputs, 4 outputs) directional coupler can similarly be formed by four $\pi/2$ hybrids as depicted in Fig. 2B. The input and output signals can be expressed the following relationships.

$$\begin{aligned} \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} &= \frac{1}{\sqrt{2}} \begin{bmatrix} T_1 & jT_1 \\ jT_1 & T_1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & j & j & -1 \\ j & 1 & -1 & j \\ j & -1 & 1 & j \\ -1 & j & j & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} \\ &= \frac{1}{\sqrt{2}} \begin{bmatrix} x_1 + jx_2 + jx_3 - x_4 \\ jx_1 + x_2 - x_3 + jx_4 \\ jx_1 - x_2 + x_3 + jx_4 \\ -x_1 + jx_2 + jx_3 + x_4 \end{bmatrix} \quad (3) \end{aligned}$$

where the coefficient -1 of x represent the opposite phase and j the $\pi/2$ phase

shift.

In general, setting $N=2^n$, an N -port directional coupler can be formed uniquely by $n2^{n-1}$ $\pi/2$ hybrids, and its transformation matrix T_n can be expressed by the following equation using T_{n-1} .

$$T_n = \frac{1}{\sqrt{2}} \begin{bmatrix} T_{n-1} & jT_{n-1} \\ jT_{n-1} & T_{n-1} \end{bmatrix} \quad (4)$$

Fig. 2C shows a modified form of the four-port directional coupler, in which the multi-port directional couplers 10 and 20 are connected in cascade and the outputs y_1, y_2, y_3 and y_4 from the first-stage directional coupler 10 are input to the second-stage directional coupler 40 to obtain the original input signals x_1, x_2, x_3 and x_4 . The matrix connection of the $\pi/2$ hybrid forming such a directional coupler is called Butler's matrix.

The conventional multi-port amplifier of Fig. 1, which utilizes the distribution of sending power among the transmission channels, uniformly divides or distributes the input power of each channel by the input side multi-port directional coupler 10 to the N channels. This permits reduction of the saturation output from each amplifier and reduction of the overall power consumption of the amplifiers of the N channels as compared with the power consumption in the case where amplifiers of N channels are each provided independently of the others. Furthermore, even if the amplifier of one of the N channels fails, the dividing of each input signal x_n (where $n=1, \dots, N$) by the input-side multi-port directional coupler 10 to N channels ensures power amplification by the amplifiers of the other channels. That is, it is known that the multi-port amplifier itself has a redundant configuration. Moreover, the overall efficiency of the multi-port amplifier improves through compression of the required output backoff by the linearizers $20_1, \dots, 20_N$.

The conventional multi-port amplifier of Fig. 1 has a configuration in

which individual amplifiers $33_1, \dots, 33_N$ of the multi-port amplifier are linearized. Each linearizer 20_n is usually a predistorter since it is provided at the input side of each amplifier. In accordance with the input signal to the amplifier the predistorter linearizes its AM/AM conversion characteristic (an
 5 input amplitude-output amplitude characteristic) and AM/PM conversion characteristic (an input amplitude-output phase characteristic). The multi-port amplifier of Fig. 1 calls for the use of the predistorter which operates in the sending frequency band.

It is of prime importance to manufacture small and light-weight
 10 N-channel transmitters. In particular, an adaptive array transmitter needs to be provided with many independent transmission channels; therefore, each transmitter must be as compact as possible. Even if the Fig. 1 multi-port configuration with predistorters are used in N transmission channels, it is necessary to form the entire channel by analog circuitry. But difficulty is
 15 encountered in implementing the whole system by one digital signal processing circuit containing a modulator and to reduce the number of parts used. To afford a sufficiently high degree of isolation between the output ports of the input side digital multi-port directional coupler 10, its gain and phase deviations between channels need to be adjusted to be sufficiently
 20 smaller than predetermined values, and the manufacture of such multi-port directional couplers in large numbers requires a circuit configuration that permits simplification of such adjustments.

SUMMARY OF THE INVENTION

25 The transmitter according to the present invention comprises:
 an input-side digital multi-port directional coupler for dividing and combining digital transmission signals of N channels by digital processing and

for outputting N-channel signals to N transmission channels, respectively;

predistorters inserted in said N transmission channels, respectively, for linearizing said N transmission channels;

transmitting parts inserted in said N transmission channels, respectively,
 5 for converting output signals from said predistorters to high-frequency signals of said N channels; and

an output-side multi-port power combiner for dividing and combining said high-frequency signals of said N-transmission channels to output high-frequency transmission signals for said N transmission channels.

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BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing the configuration of a conventional multi-port amplifier;

Fig. 2A is a diagram explanatory of a $\pi/2$ hybrid;

15 Fig. 2B is a block diagram showing the configuration of a four-port directional coupler;

Fig. 2C is a diagram explanatory of a cascade connection of directional couplers;

20 Fig. 3 is a block diagram illustrating a basic functional configuration of the transmitter according to the present invention;

Fig. 4 is a block diagram depicting a first embodiment of the transmitter according to the present invention;

Fig. 5 is a block diagram showing an example of the configuration of a transmitting part;

25 Fig. 6 is a block diagram showing an example of the configuration of a receiving part;

Fig. 7 is a block diagram depicting an example of the configuration of a

predistorter;

Fig. 8 is a block diagram depicting a second embodiment of the transmitter according to the present invention; and

Fig. 9 is a block diagram depicting a third embodiment of the transmitter according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 3 illustrates a basic functional configuration of the transmitter according to the present invention. The transmitter comprises: an input side digital multi-port directional coupler 13 which divides and combines input digital signals of N channels to provide output signals of N channels; predistorters $21_1, \dots, 21_N$ which impart compensating distortions to the N-channel output signals, respectively; digital-to-analog (DA) converters $22_1, \dots, 22_N$ which convert the outputs to analog signals; transmitting parts $30_1, \dots, 30_N$ which output the outputs from the DA converters as high-frequency signals; and an output side multi-port directional coupler 40 which divides and combines the outputs from the N-channel transmitting parts and sends N-channel high-frequency signals to N antennas (not shown), respectively.

As will be seen from the above, in the present invention the signal processing by the input side digital multi-port directional coupler 13 and the predistorters $21_1, \dots, 21_N$ is digital processing. By performing the function of the multi-port directional coupler 13 through digital processing, it is possible to achieve characteristics of the multi-port directional coupler with ideal gain and phase deviations.

In the following description, letting discrete time t be represented by $t=mT$, where T is the sample period T [sec] of a digital signal and m is a positive number, and letting the input signal $x_n(m)$ of an n th channel be

represented by a complex amplitude, the input signal to the input side digital multi-port directional coupler 13 is expressed by the following matrix.

$$\mathbf{X}(m) = (x_1(m)x_2(m), \dots, x_N(m))^T \quad (5)$$

where T represents a transposition. The input signal $\mathbf{X}(m)$ is transformed by the N-channel input side digital multi-port directional coupler 13 through use of Eq. (4) to an output signal $\mathbf{Y}(m)$ as given by the following equations.

$$\mathbf{Y}(m) = \mathbf{T}_n \mathbf{X}(m) \quad (6)$$

$$\mathbf{Y}(m) = (y_0(m)y_1(m), \dots, y_{N-1}(m))^T \quad (7)$$

Letting \mathbf{F} represent a waveform transformation matrix of predistorters 21₁, ..., 21_N, $\mathbf{Y}(m)$ is transformed to $\mathbf{Z}(m)$.

$$\mathbf{Z}(m) = \mathbf{F}(\mathbf{Y}(m))\mathbf{Y}(m) \quad (8)$$

$$\mathbf{Z}(m) = \begin{bmatrix} f(y_0(m)) & 0 & 0 & 0 \\ 0 & f(y_1(m)) & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & f(y_{N-1}(m)) \end{bmatrix} \begin{bmatrix} y_0(m) \\ y_1(m) \\ \vdots \\ y_{N-1}(m) \end{bmatrix} \quad (9)$$

The signal $\mathbf{Z}(m)$ is used to perform processing in the input side digital multi-port directional coupler 13 and the predistorters 21₁, ..., 21_N by digital signal processing. Let $\mathbf{Z}(t)$ represent a matrix of analog signals converted by the DA converters 22₁, ..., 22_N from the signal $\mathbf{Z}(m)$. Respective elements of the signal matrix $\mathbf{Z}(t)$ are subjected to frequency conversion to the transmission frequency band and power amplification in the transmitting parts 30₁, ..., 30_N. The power-amplified signals of N channels are transformed by the output side multi-port directional coupler 40 to transmission signals $\mathbf{U}(t) = (u_1(t), \dots, u_N(t))$.

The predistorters 21₁, ..., 21_N monitor the amplified output signals and adaptively update the coefficients of the waveform transformation matrix \mathbf{F} by digital processing so as to achieve predetermined nonlinear distortion

characteristics.

The production of the signal $Z(m)$ by the above processing allows complete elimination of imperfection of the operating characteristic of the input side multi-port directional coupler 13 formed by analog circuitry.

5 Further, it is possible to perform generation of the signals $X(m)$ to $Z(m)$ by digital signal processing. Since the above-described digital signal processing can be achieved by such software as DSP (Digital Signal Processor), the circuit configuration by the present invention can be implemented with more ease than the conventional configuration analog circuitry. Besides, since the input
10 side multi-port directional coupler, which is formed by an analog circuit in the prior art, is implemented by digital signal processing, the gain and phase deviations between the output ports can be reduced to zero. Zeroing the gain and phase deviations in the analog circuit configuration is impossible in terms of circuit fabrication accuracy. Accordingly, digital signal processing permits
15 simplification of the circuit adjustment as compared with the conventional analog circuit configuration.

FIRST EMBODIMENT

Fig. 4 illustrates the configuration of a first embodiment of the
20 transmitter according to the present invention.

The transmitter comprises: encoders $12_1, \dots, 12_N$ of N channels; an input side digital multi-port directional coupler 13; predistorters $21_1, \dots, 21_N$; quadrature modulators $23_1, \dots, 23_N$; DA converters $22_1, \dots, 22_N$; transmitting
25 parts $30_1, \dots, 30_N$; an output side multi-port directional coupler 40; receiving parts $50_1, \dots, 50_N$; and analog-to-digital (AD) converters $60_1, \dots, 60_N$.

The encoders $12_1, \dots, 12_N$ perform QPSK (Quadrature Phase Shift Keying) or similar encoding of a transmission digital signal sequence provided

to input terminals $11_1, \dots, 11_N$.

The input side digital multi-port directional coupler 13 inputs thereto complex signals of N channels and outputs complex signals of N channels. The processing in the input digital multi-port directional coupler 13 calculates
 5 Eq. (6) through use of the matrix defined by Eqs. (4) and (5). That is, the input side digital multi-port directional coupler 13 performs processing which multiplies the input signal matrix by the transformation matrix T_n starting at the left-hand side. The complex output signals of the respective channels y_1, \dots, y_N from the input side digital multi-port directional coupler 13 are fed to
 10 the predistorters $21_1, \dots, 21_N$, respectively.

Each predistorter 21_n (where $n=1, \dots, N$) linearizes gain and phase characteristics of the signal of the corresponding channel by preimparting thereto a compensating distortion which cancels the nonlinear distortion generated by a power amplifier (Fig. 5, described later on) in the transmitting
 15 part 30_n . The configuration of the predistorter 21_n is a conventional look up table type or cuber distortion compensating type based on a power series model. The output signal from each predistorter 21_n is subjected to quadrature modulation by digital signal processing in the quadrature modulator 23_n . The output signal from the quadrature modulator 23_n is converted by the
 20 DA converter 22_n to an analog signal, which is provided to the transmitting part 30_n .

For example, as identified generally by 30 in Fig. 5, each transmitting part 30_n comprises: a frequency up-converting part 31 made up of a band-limiting low-pass filter 31A, a mixer 31B and a local oscillator 31C; a
 25 band-pass filter 32; and a power amplifier 33. In the transmitting part 30 the AD converter output signal is up-converted by being mixed with a high-frequency (RF) carrier signal generated by the local oscillator 31C, and a

signal of the RF transmission frequency band is extracted by the band-pass filter 32 and subjected to power amplification by the power amplifier 33. The power-amplified high-frequency transmission signal is transmitted via an antenna 42_n. For example, as identified generally by 50 in Fig. 6, each receiving part 50_n comprises: a detecting part 51 made up of an attenuator 51A, a mixer 51B and a local oscillator 51C; a band-pass filter 52; and a control part 53.

As depicted in Fig. 6, in each receiving part 50_n a portion of the power of the output signal from the transmitting part 30_n of the corresponding channel is detected by the mixer 51B and the local oscillator 51C via the attenuator 51A, and the detected signal is applied to the band-pass filter 52 to extract the distortion component generated by the power amplifier 33. Based on the extracted distortion component, the control part 53 generates a correcting signal, which is provided to the AD converter 61_n (Fig. 4). The correcting signal converted by the AC converter 61_n to digital form is applied to the predistorter 21_n to adjust its gain and phase characteristics to minimize the above-mentioned extracted distortion component, providing predetermined linearity of the transmitting part 30_n.

Fig. 7 illustrates in block form an example of the predistorter 21_n (identified by 21). A wide variety of predistorters have already been proposed; the predistorter of this example is a digital predistorter using a power series model. The illustrated predistorter is configured to add together signals from a delay path which passes therethrough the fundamental wave component of the transmission signal, and on a path for generating an odd-order distortion based on power series. That is, the predistorter 21 of this example is made up of a delay part 21A, a distortion generator 21B, a phase adjuster 21C, a gain adjuster 21D and an adder 21E. The fundamental wave

component of the transmission signal is fed to the adder 21E via the delay part 21A wherein it is delayed by the same time interval as the delay time of the distortion generating path. The distortion generator 21B generates a power series-based odd-order distortion, for example, third-order distortion, of the transmission signal. This odd-order distortion is adjusted in phase by the phase adjuster 21C and then adjusted in gain by the gain adjuster 21D, thereafter being added to the fundamental wave component by the adder 21E. The adder output is provided as the output from the predistorter 21 to the transmitting part 30_n via quadrature modulator 23_n and the DA converter 22_n of the corresponding channel. Incidentally, the distortion generator may be configured to generate the third-, fifth-, or seventh-order distortion, or a desired combination of them.

By the phase and gain correcting signals provided thereto via the AD converter 60_n (Fig. 4) from the control part 53 of the receiving part 50, the phase adjuster 21C and the gain adjuster 21D are adjusted to adjust the phase and gain of the odd-order distortion. The correcting signals provide coefficients for adjusting the phase adjuster 21C and the gain adjuster 21D, and define the waveform transformation matrix F of the predistorter in Eqs. (8) and (9). The control part 53 may also be implemented by digital signal processing. In such an instance, each AD converter 60_n in Figs. 4 and 8 is inserted between the band-pass filter 52 and the control part 53 in the receiving part 50_n of Fig. 6 to convert the distortion component extracted by the band-pass filter 52 to a digital signal, and the control part 53 generates a digital correcting signal based on the digital distortion component.

In the Fig. 4 embodiment the encoders $12_1, \dots, 12_N$ to the quadrature modulators $23_1, \dots, 23_N$ are implemented by integrated digital signal processing. For example, in the case of a digital signal processing system

which operates in real time, the functions of the encoders $12_1, \dots, 12_N$ to the quadrature modulators $23_1, \dots, 23_N$ can be implemented as software. It is also possible to implement the functions of the encoders $12_1, \dots, 12_N$ to the quadrature modulators $23_1, \dots, 23_N$ by use of such hardware logic as FPGA (Field Programmable Gate Array). This embodiment permits programmable implementation of the functions of the encoders $12_1, \dots, 12_N$ to the quadrature modulators $12_1, \dots, 23_N$, and allows resetting of their functions adaptively or according to the circumstances. Accordingly, it is possible to cope with a plurality of modulation schemes and a plurality of predistortion schemes by use of the same DSP or FPGA hardware configuration. The input side digital multi-port directional coupler 13 and the predistorters $21_1, \dots, 21_N$ may also be implemented by independent control programs. Besides, the control programs for the input side multi-port directional coupler 13 and the predistorters $21_1, \dots, 21_N$ may be implemented by a single controller.

In the conventional multi-port amplifier configuration the input side digital multi-port directional coupler 13 and the output side multi-port directional coupler 40 are both implemented by analog circuits. The present invention implements the input side digital multi-port directional coupler 13 by digital signal processing as expressed by Eqs. (5) and (6). This eliminates the need for adjusting the gain and phase deviations between respective channels to be smaller than design values so as to provide a predetermined or greater degree of isolation between the output ports of the input side multi-port directional coupler as required in the prior art. That is, the present invention ensures complete isolation between the output ports of the input side directional coupler without any adjustment and hence enables the gain and phase deviations to be made zero. Accordingly, the present invention needs only adjustment of the output side multi-port directional coupler and provides

an increased degree of isolation of the multi-port configuration by less adjustment than in the prior art.

SECOND EMBODIMENT

5 Fig. 8 illustrates in block form a second embodiment of the transmitter according to the present invention.

 The illustrated transmitter comprises: quadrature modulators $14_1, \dots, 14_N$ for quadrature modulation of input digital IQ signals; an input side digital multi-port directional coupler 13; predistorters $21_1, \dots, 21_N$; DA converters $22_1, \dots, 22_N$; transmitting parts $30_1, \dots, 30_N$; an output side multi-port directional
10 coupler 40; receiving parts $50_1, \dots, 50_N$; and AD converters $60_1, \dots, 60_N$. Each transmitting part 30_N has the afore-mentioned configuration of Fig. 5, each receiving part 50_N has the afore-mentioned configuration of Fig. 6, and each predistorter 21_N has the afore-mentioned configuration of Fig. 7. This
15 embodiment is identical in construction with the Fig. 4 embodiment except the above.

 This embodiment differs from the first embodiment in that the input digital multi-port directional coupler 13 and the predistorters $21_1, \dots, 21_N$ perform processing of the digital signals x_1, \dots, x_N subjected to quadrature
20 modulation by the quadrature modulators $14_1, \dots, 14_N$. This embodiment is identical in operation and effect with the first embodiment. The configurations of the first and second embodiments implement the input side digital multi-port directional coupler 13 and the predistorters $21_1, \dots, 21_N$ through digital signal processing, thereby permitting simplification,
25 miniaturization and weight reduction of the device configuration as compared with the conventional multi-port configuration.

THIRD EMBODIMENT

Fig. 9 illustrates in block form of the Fig. 8 embodiment. While the first and second embodiments have been described to implement the predistorters $21_1, \dots, 21_N$ by digital signal processing, they may also be formed by analog circuits as depicted in Fig. 9. In this case, the predistorters $21_1, \dots, 21_N$ are inserted between the DA converters $22_1, \dots, 22_N$ and the transmitting parts $30_1, \dots, 30_N$, respectively, and the distortion components extracted in the receiving parts $50_1, \dots, 50_N$ are applied as correcting signals in analog form to the predistorters $21_1, \dots, 21_N$, respectively. In this embodiment, since the predistorters $21_1, \dots, 21_N$ are formed by analog circuits, the transmitter configuration becomes larger than in the case of the Fig. 8 embodiment, but digital processing in the input side digital multi-port directional coupler 13 produces the intended effect.

In the first, second and third embodiments adaptive array antenna or sector antenna can be used as each of the antennas $42_1, \dots, 42_N$ which are supplied with the output from the output side multi-port directional coupler 40. Further, a duplexer or switch commonly used in radio stations may also be provided between the output side multi-port directional coupler 40 and each of the antennas $42_1, \dots, 42_N$ so that a receiver (not shown) is used also as an antenna.

EFFECT OF THE INVENTION

As described above, according to the present invention, the implementation of the input-side multi-port directional coupler and the predistorters by digital signal processing produces such effects as (1) miniaturization of the transmitter and (2) facilitation of adjustment of the multi-port configuration.